Spurck & Wheatlake

The design and construction of a practical wireless telegraph station

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THE DESIGN AND CONSTRUCTION OF A PRACTICAL WIRELESS TELEGRAPH STATION

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THESIS

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IN

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

ROBERT MICHAEL SPURCK and BURTON CYRENIUS JOB WHEATLAKE

ENTITLED THE DESIGN AND CONSTRUCTION OF A PRACTICAL WIRELESS TELEGRAPH STATION.

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF BACHELOR OF SCIENCE in ELECTRICAL ENGINEERING

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THE DESIGN AND CONSTRUCTION OF A PRACTICAL WIRELESS TELEGRAPH STATION.

Introduction.

During the last few years wireless telegraphy has reached the point where it is no longer considered an interesting experiment, but now takes its place among the world's most practical discoveries.

To no one person can be given the credit for the development of this practical application of science. While Messrs. Marcroni, De Forrest, Count Arco and others are particularly prominent in the present day development, still more credit is due Hertz for his classical exposition of the fundamental laws of electro-wave transmission. Like many other great investigators he died before the true value of his labors was evident.

In recent years the greatest activity has been in the development of detectors. Perhaps in the future more attention will be given to the sending apparatus.[1] If waves of 0.040 of an inch or less can be produced they will be seen as colors by the eye, and no other detector will be necessary.

Resume.

The first hint of the existence of electromagnetic waves was given by Professor J. Clerk Maxwell of Cambridge, who, struck by the value of a certain coefficient, very important in the study of electrical phenomena, and by its agreement with the

1. Smithsonian Report 1898, Page 250.

figure which represents the velocity of the propagation of light, was strongly impressed with the extreme likelihood that light and electricity were essentially the same. Building upon this apparent identity, he worked out an hypothesis in regard to the constitution of the medium in which these phenomena exist. Later his mathematical deductions were verified experimentally by Heinrich Hertz.

Hertz's investigations in the field of electric waves took place mostly between dates November, 1887 and December, 1889. While attempting to prove the relation between "Electro-dynamic Forces and Dielectric Polarisation in Insulators",[1] he became interested in electric waves in general.

Perhaps the direct cause which started him on the road to his investigations was the accidental discovery that the discharge of a Leyden jar or induction coil through a coil of insulated wire would incite induced currents in a similar coil provided there was a spark gap in the first. This then gave a method of detecting electric waves in space.

In his paper, "On Very Rapid Electric Oscillations", he occupied himself with some of these phenomena. His exciter consisted of simple rods to the ends of which were fixed metallic squares. Figure (1)

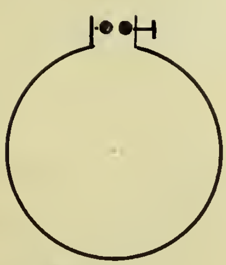

Figure 2.

Figure 1.

1. Fahie---- History of Wireless Telegraphy, Page 179.

A spark gap was provided in the center. In his experiments this exciter was charged by an induction coil.

The detector (Figure 2) consisted of a wire bent in a circle having a spark gap similar to that of the exciter circuit, but provided with a micrometer for measuring the gap. The length of the spark gap in the detector indicating the intensity of the received wave impacts. For a given adjustment of the exciting current the system is said to be in resonance or electrically tuned, when the dimensions of the detector are such as to give maximum sparks.

It was seen that the length and brightness of the sparks at the detector were affected by the sparks of the exciter. If the exciter spark gap was visible from the detector spark gap the sparks in the latter were smaller, but when a screen was placed between the two instruments they became brighter again. This action was caused by ultra-violet light from the exciter breaking down the insulation of the detector spark gap.[1]

His next paper was "On the Action of Rectilinear Electric Oscillation on a Neighboring Circuit" The detector was placed in various positions with respect to the exciter and the effects studied and measured by the adjustable spark gap. The conclusion reached was that electric waves have the same law of radiation as light.

In his paper, "On the Velocity of Propagation of Electro-dynamic Actions", Hertz shows that alternating currents of high frequency, such as 100,000,000 per second, are confined only to the surface of the conductor. This is commonly called "skin effect".

1. Fahie -- History of Wireless Telegraphy, Page 182.
This means that Ultra-Violet light decreases the discharge E.M.F.

Maxwell's theory of light as applied to electric waves was supported in the next paper, "On Electric Radiation". Waves thirty centimeters in length were collected by a concave mirror and concentrated into a single beam of electric radiation. He demonstrated that these rays were propagated in straight lines like light, and showed that they would not pass through metals but were reflected from them. However they were able to penetrate wood, stone and like materials. By setting up metallic screens electric shadows were formed behind them. He was able to polarize them by the use of a wire grating and also proved that these beams could be refracted by a prism of pitch.

For sometime after Hertz most of the work was done in developing the coherer.

As early as 1850 Guitard noticed that electrified dust particles tended to cohere in strings. Mr. S. A. Varley made practical application of this in his lightning arrester in 1870. Coherence of electrified particles was also independently noticed by Signor Calzechi-Onesti in 1885. All of the above were forgotten until 1890 when Professor E. Branly discovered that the resistance of metallic filings falls from millions to hundreds of ohms when a Leyden jar is discharged in its vicinity.

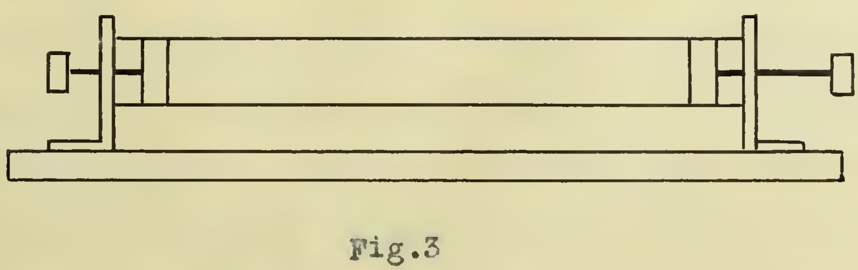

Fig.3

Sir Oliver Lodge was the first to recognize the importance of the Branly coherer and apply it to the discoveries made by Hertz. The first form of his coherer, (see Figure 3) consisted of a glass tube about seven inches long and one half inch in diameter, fitted with copper pistons adjustable to give any required pressure to the metallic filings enclosed within the tube. A mechanical tapper was used for decohering. Lodge[1] however did not see the application of this instrument to long distance telegraphy but confined his work to distances up to one hundred and fifty yards.

Nevertheless he demonstrated his discoveries in a lecture "On the Work of Hertz and his Successors", which incited to action many men who afterwards made notable improvements in spark telegraphy. Among these may be mentioned Muirhead, Jackson, Trelfal and Popoff.

Up to the year 1896 the application of the Hertz exciter and Branly receiver to sending and receiving of messages through space had been studied by physicists of the world but no one had conquered the real practical difficulties and exhibited a process in actual operation until Marcroni appeared and showed the world how.

Marcroni was born in Bologna and studied under Professor Righi who was a disciple of Hertz and had done much work on electro-magnetic radiation. It was probably through Righi that Marcroni became interested in the Hertzian discoveries and bent his energies to the practical application of the discoveries to telegraphy without wires. During the years 1895-1896 he did much experimenting with the Branly coherer, and developed a new

1. Wireless Telegraphy -- Story, Page 107.

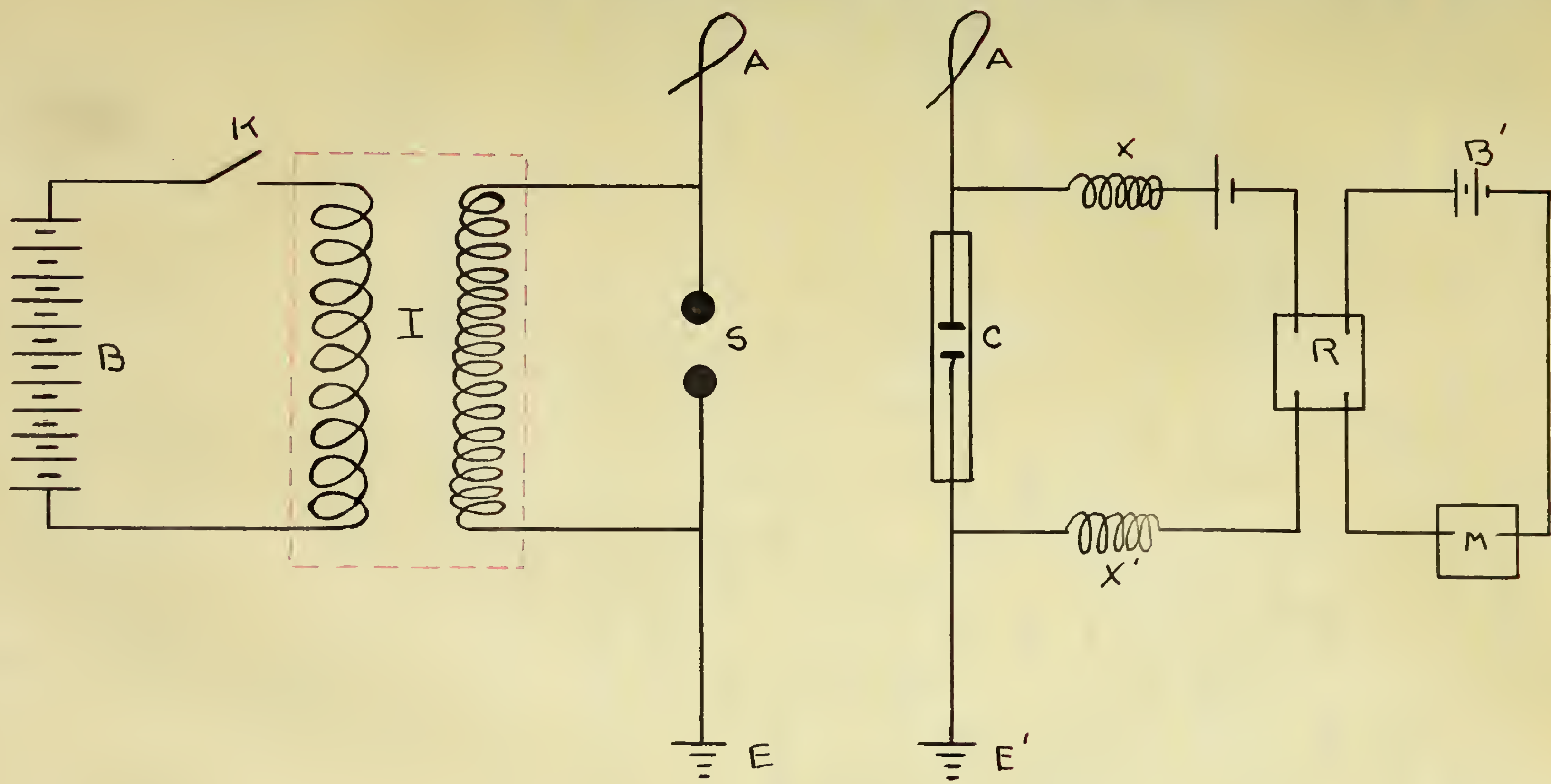

Fig. 4

B, B' - Batteries	A,A' - Aerial
K - Key	C - Coherer
I - Induction Coil	X,X' - Choke Coils
S - Spark Gap	R - Relay
E,E' - Earths	M - Sounder

kind of wave radiator. So successful were his experiments that in July 1896 he was able to demonstrate his finished apparatus before Sir William Preece, then engineer-in-chief to the British Postal Telegraph Department, who for twelve years previous had been interested in the development of wireless telegraphy by the inductive conductive system. Apparatus shown in Figure 4.

In the sending circuit, which took the place of the Hertz exciter, one end of the spark gap was connected to the earth while the other was attached to a tin foil covered kite. At the receiving end instead of the micrometer spark gap of Hertz a modified form of the Branly coherer was used, one end of which was earthed the other being connetced to a kite similar to the one used at the sending station. The coherer (See Figure 5) consisted of a glass tube one and one half inches long and one fourth inch inside diameter in which were placed two silver plugs fitting the tube tightly. The inner faces of these plugs were polished and slightly amalgamated. Between them were some nickel and silver ninty five per cent nickel and five per cent silver.

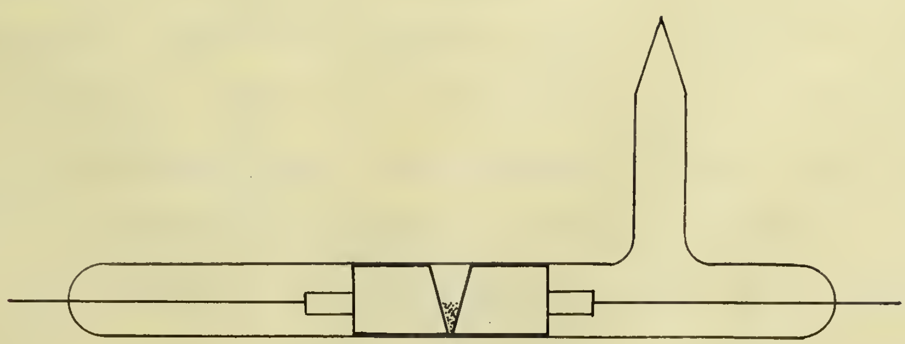

Fig. 5

The whole tube was exhausted and connections sealed in. By beveling the inner faces of the plugs it was possible to regulate the sensitiveness by rotating the instrument around on its horizontal axis.

This instrument was many times more sensitive than the larger instrument made previously by Branly.

As key K at the sending end is closed a spark passes across the spark gap (S) causing waves to be disseminated in all directions from the kite. These waves are intercepted by the kite at the receiving end and are conducted through the coherer to the earth, reducing the coherer resistance so that current from the battery B' will flow through it and opperate the sounder. [1]Much discussion has taken place upon the exact nature of the processes at work when electric oscillation passes through an imperfect contact, as a coherer. The original idea was that the effects were due to thermal actions, heat being developed at the imperfect contact which welded together the junction. This hypothesis, however, fails to explain the contact action when such unweldable substances as carbon or other non-metallic conductors are employed. Also it does not explain the decreased conductivity in the case of a lead and peroxide of lead junction. When the oscillations begin to take place across the junction there is a certain difference of potential between the points or surfaces in imperfect contact. We may think of the surfaces as initially separated by an extremely thin film of air and forming therefore a condenser of small capacity. Another view, therefore, taken of the effect is that

1. Fleming- Radiotelegraphy page 187.

the electrostatic attraction between these surfaces squeezes out the air and brings the surfaces into molecular contact, thus effecting an improved conductivity. At present, however our knowledge of the true nature of electric induction and of the reasons some substances are better conductors than others is too imperfect to enable us to account for the fact that the oscillation passing across a loose contact between two surfaces do not always cause an increase of conductivity. Neither the welding theory nor the electrostatic attraction theory explain why the magnetic metals, particularly nickel, are so much better than most others in making imperfect contact oscillation detectors. In spite of much research, therefore the scientific problems in connection with this coherer action are by no means solved.

The coherer is made to assume its original condition by rapping with a mechanical tapper.

Improvements were rapidly made on the original apparatus and instead of kites fixed wire nets or capacity areas were used as aerials and their shape varied. The coherer was no longer connected directly between the earth and the aerial but the jigger took its place and the coherer was connected to a separate winding on the jigger. In reality the jigger is an air cored transformer, (See Figure 6) the primary winding is connected between the earth and aerial and the fine winding is connected to the coherer. There are many modifications of the jigger such as splitting the fine winding and inserting a capacity.

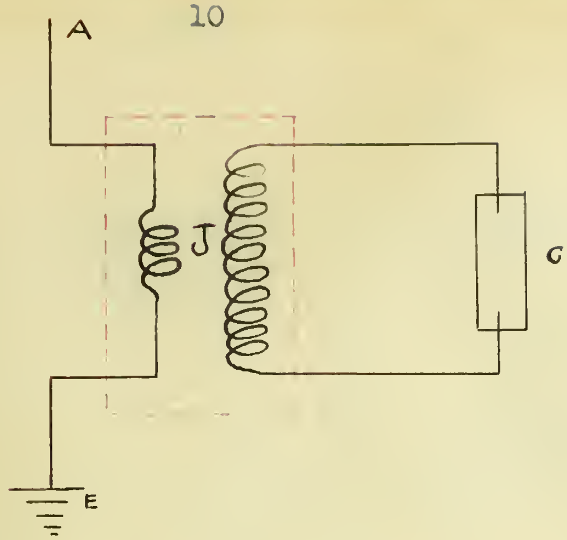

Fig. 6

[1]The efficiency of the above described apparatus is increased very much by making it syntonic. If an oscillatory circuit has a periodic or alternating electromotive force set up in it and if the frequency of this electromotive force agrees with the natural frequency of the circuit, then an immensely greater current will be produced than if the periods do not agree. This increase in the amplitude of the alternating current created in the circuit by exactly syntoizing the frequency of the impressed E. M. F. with the natural frequency is said to be due to electrical resonance. It is a well known fact that a very considerable amplitude of vibration can be set up in a pendulum by administering to it small blows, provided these are timed to agree exactly with the natural period of the pendulum.

In wireless telegraphy the sending circuit is made resonant by making the frequency of the spark gap circuit agree with the natural period of the aerial circuit, this period being determined by the capacity and inductance of the circuit. The

1. Fleming- Page 32.

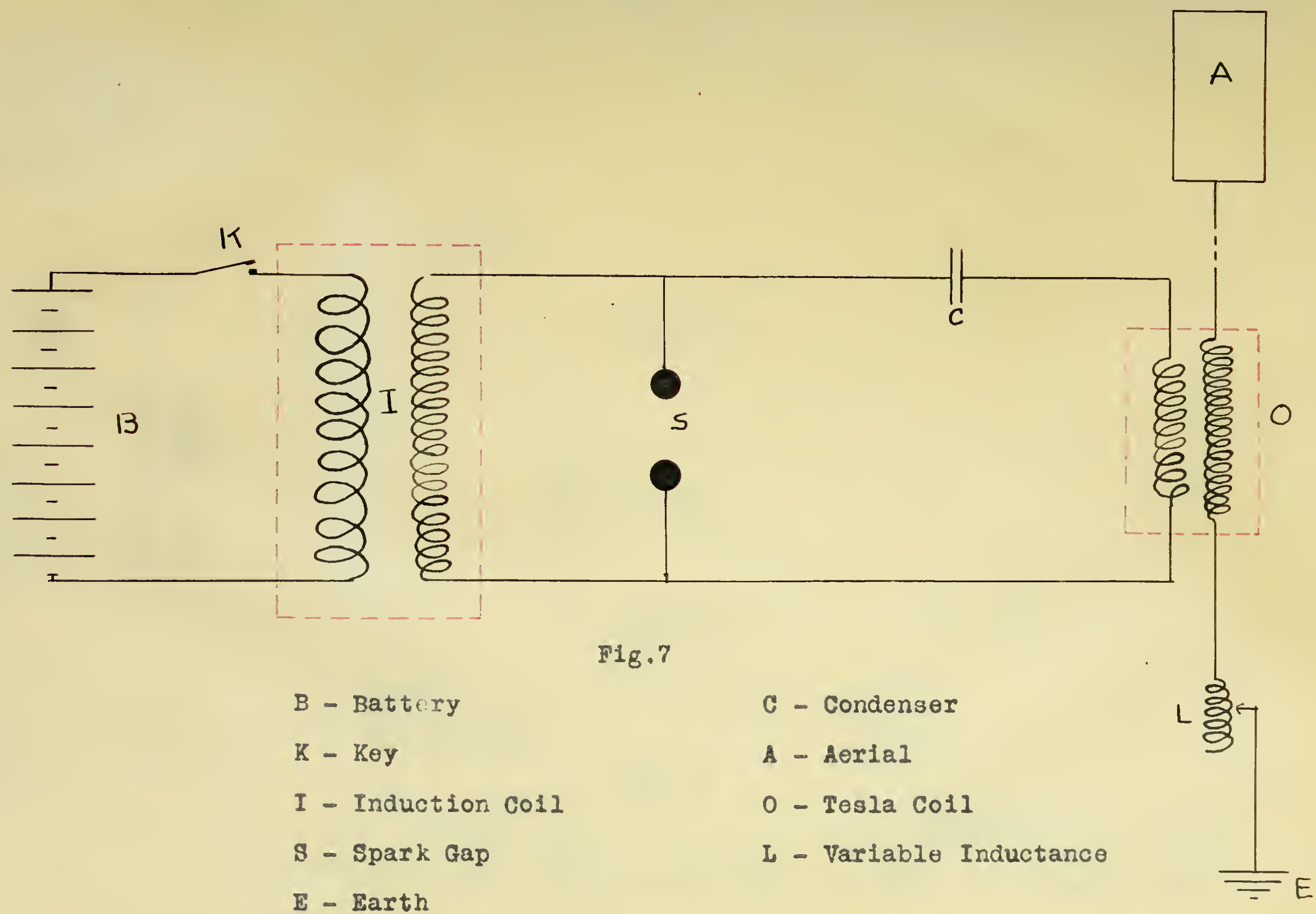

Fig.7

B - Battery

K - Key

I - Induction Coil

S - Spark Gap

E - Earth

C - Condenser

A - Aerial

O - Tesla Coil

L - Variable Inductance

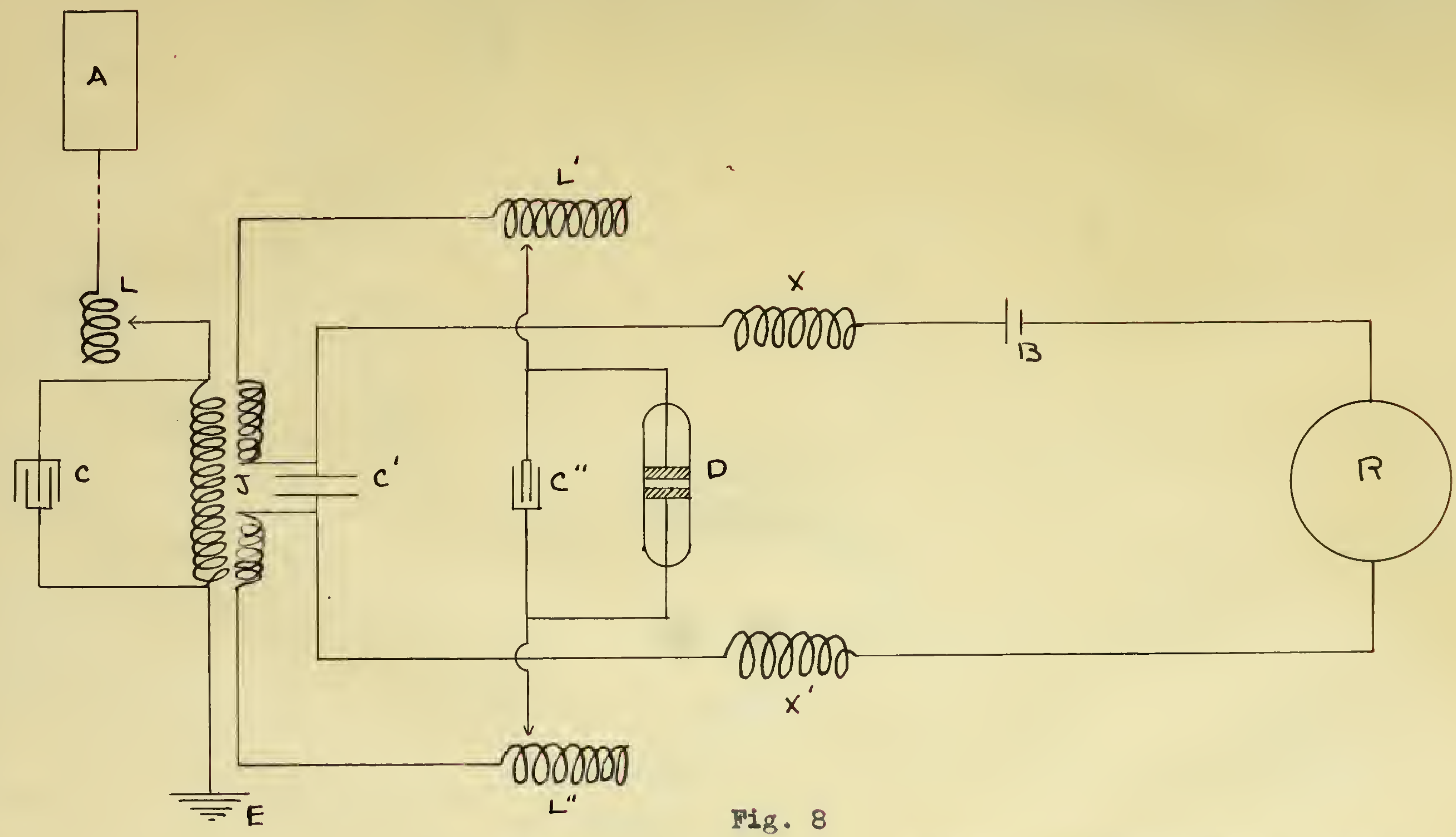

Fig. 8

A - Aerial	X,X' - Choke Coils	E - Earth
L, L', L''- Variable Inductance	R - Relay	D - Detector
C, C', C''- Capacities	J - Jigger	B - Battery

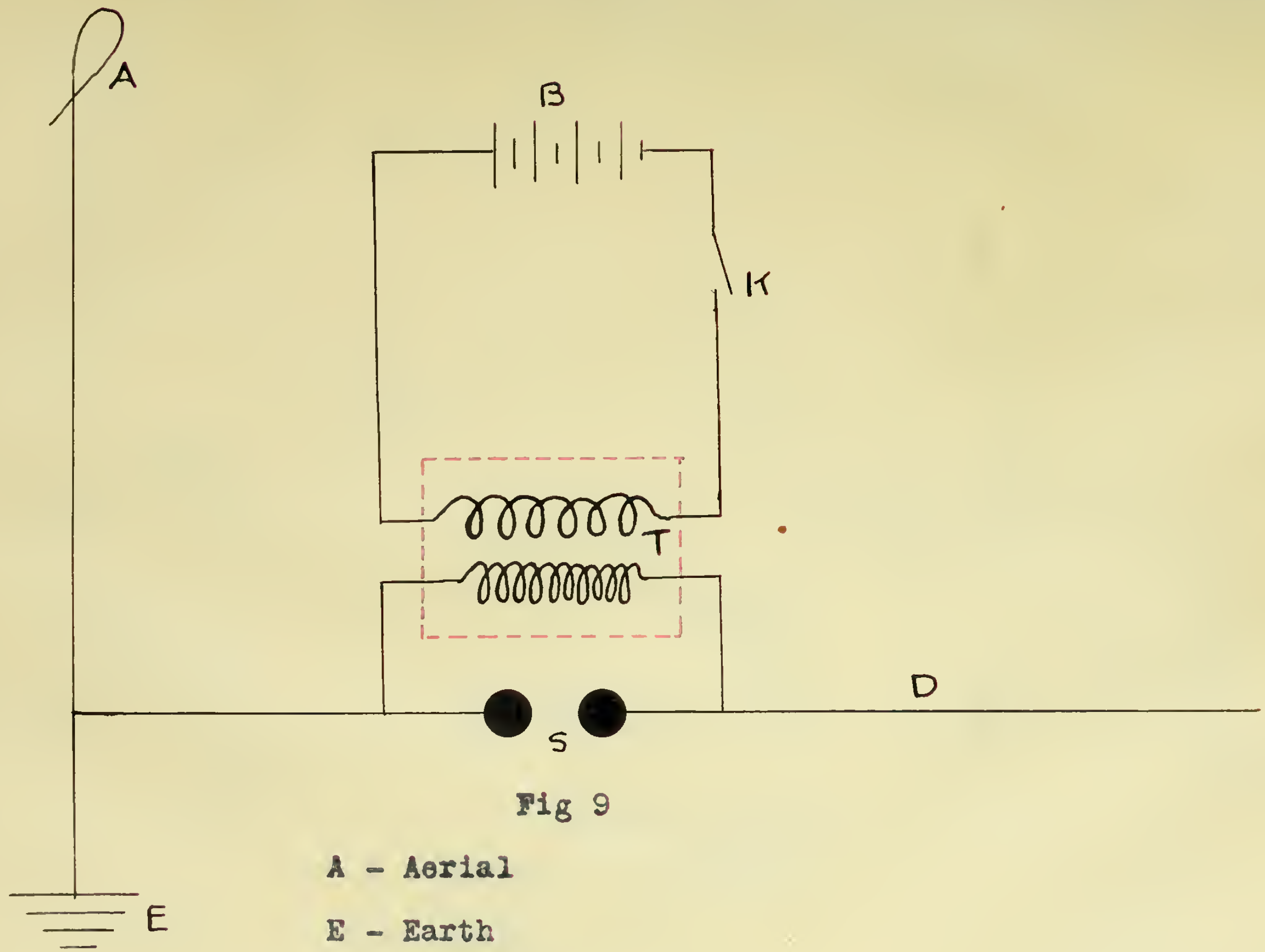

Fig 9

A - Aerial

E - Earth

S - Spark Gap

T - Induction Coil

D - Side Wire

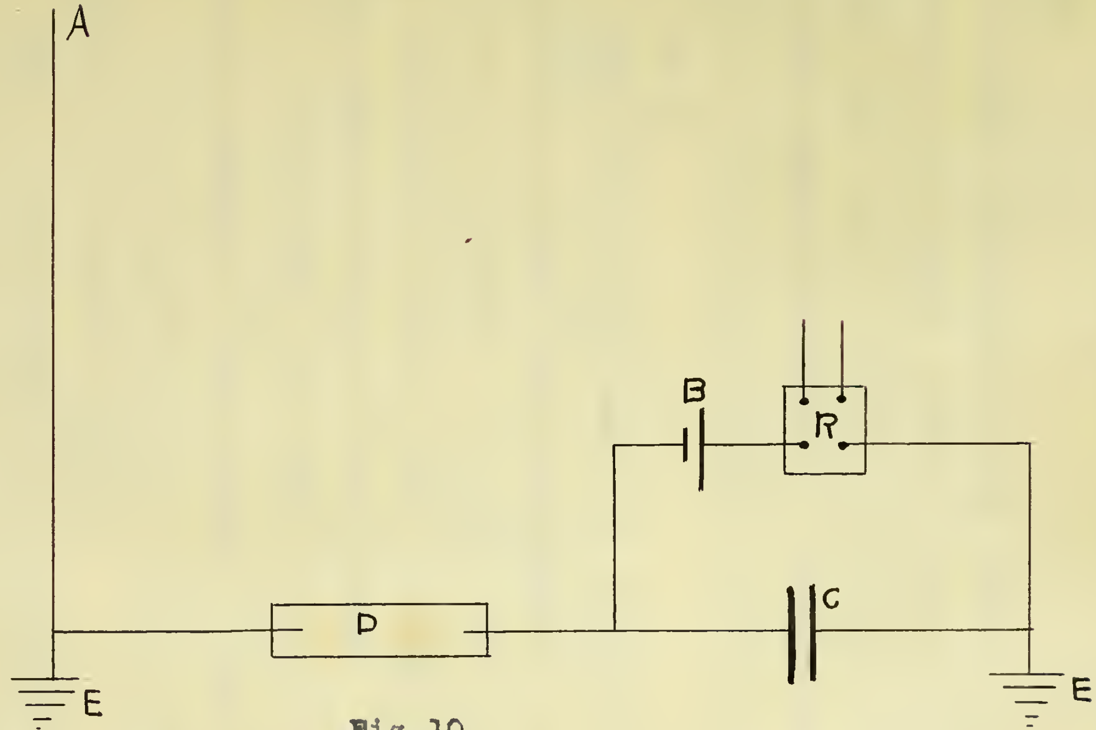

Fig 10

A - Aerial

E - Earth

D - Detector

B - Battery

C - Condenser

R - Relay

natural frequency "f" of any circuit equals $2\pi\sqrt{LC}$ where L is the inductance and C the capacity of the circuit expresses in absolute units. For most efficient opperation the natural frequency of the sending aerial should be exactly that of the receiving aerial.

The Marcroni system is made syntonic by placing a variable inductance in the aerial circuit of both the sending and receiving ends, which has the effect of changing the length of the aerial and permits the sending of variable wave lengths. The circuits for the Marcroni syntonic system are shown in (Figures 7 and 8).

After Marcroni had shown the application of Hertz's work to be practical, Lodge began improvements on coherers and worked on syntonic telegraphy. He soon formed a partnership with Dr. A. Muirhead, the result being the Lodge Muirhead System and the Lodge Muirhead Mercury steel coherer.

Dr. Adolph Slaby and Count Von Arco soon realized the inefficient position of the Marcroni coherer and remedied this defect in a very ingenious manner. Their system is shown diagrammatically in figures 9 and 10.

Tesla in 1892 brought out an oscillation transformer known as the Tesla coil for producing long trains of high frequency waves. This is nothing more than an air cored transformer built to withstand a high voltage and its high potential and frequency is due to the fact that it is placed outside the spark gap. An arrangement of apparatus including a Tesla coil is shown in Figure 11.

Among the later men who might be mentioned in the de-

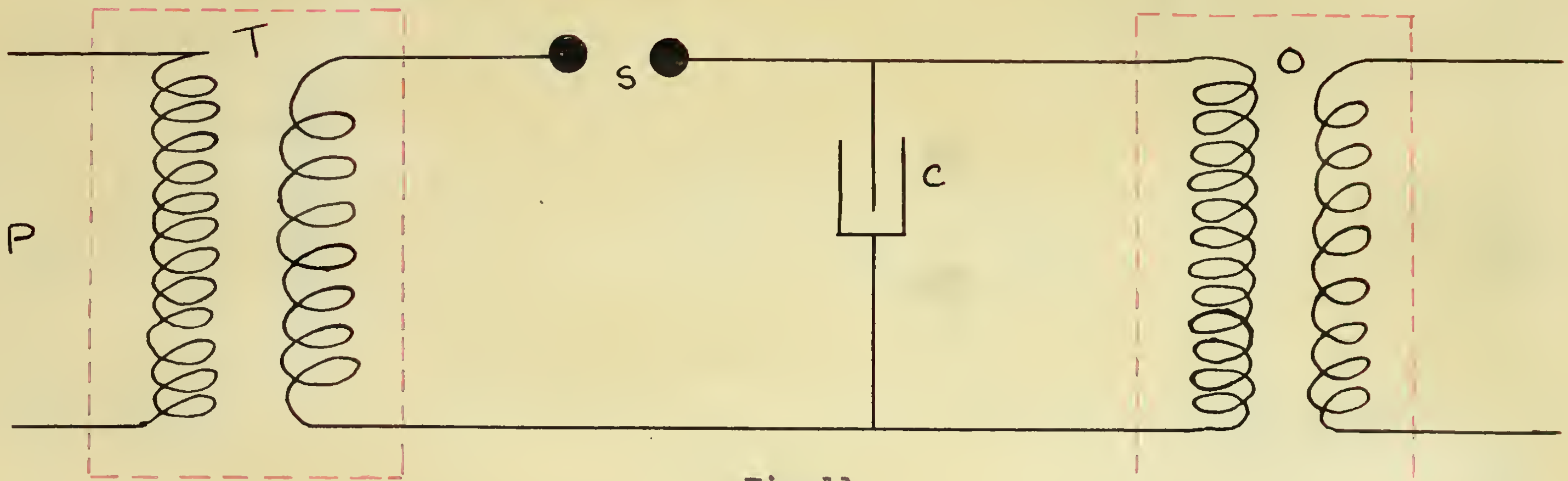

Fig 11

T - Transformer

P - Source of Power

S - Spark Gap

C - Condenser

O - Tesla Coil

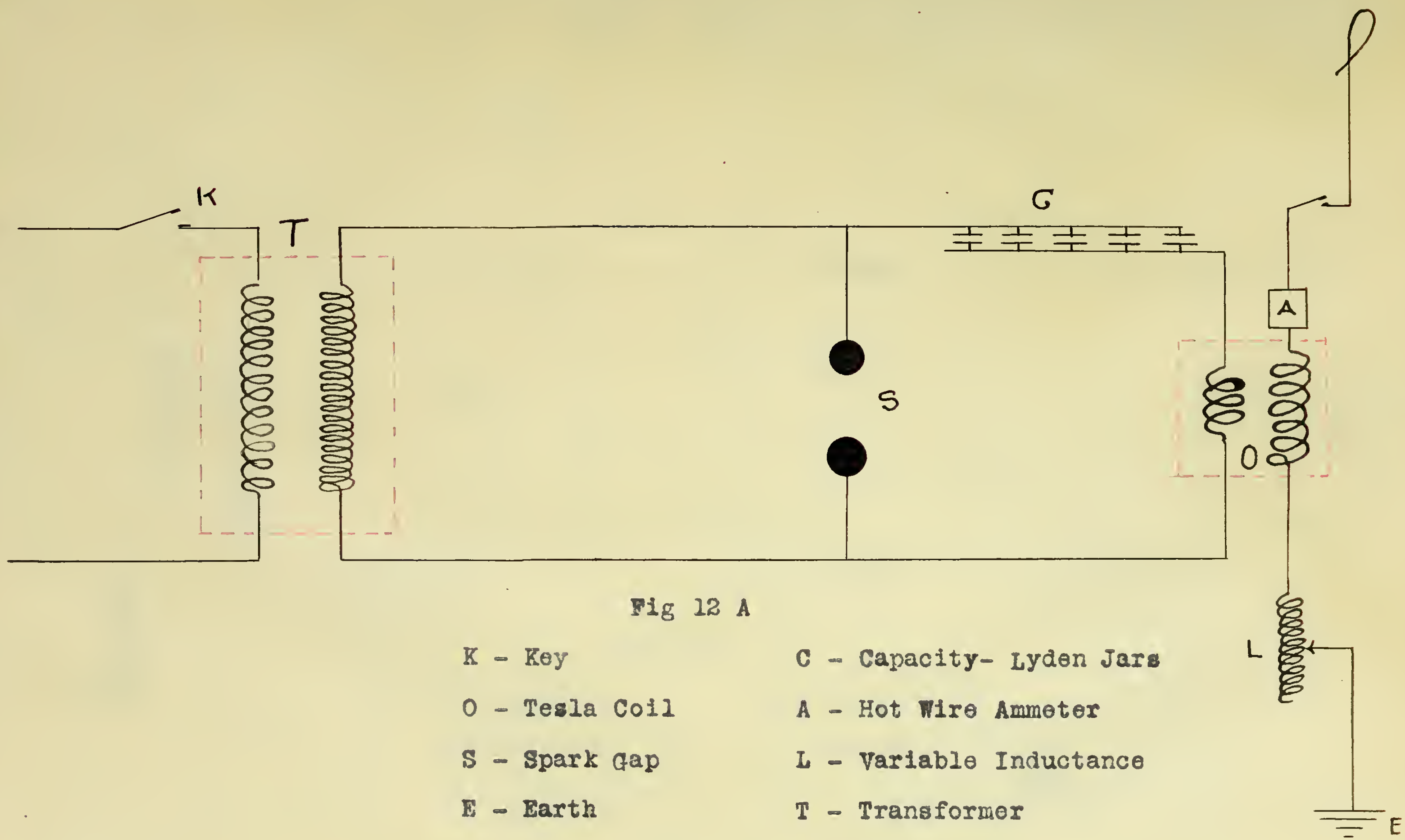

Fig 12 A

K - Key	C - Capacity- Lyden Jars
O - Tesla Coil	A - Hot Wire Ammeter
S - Spark Gap	L - Variable Inductance
E - Earth	T - Transformer

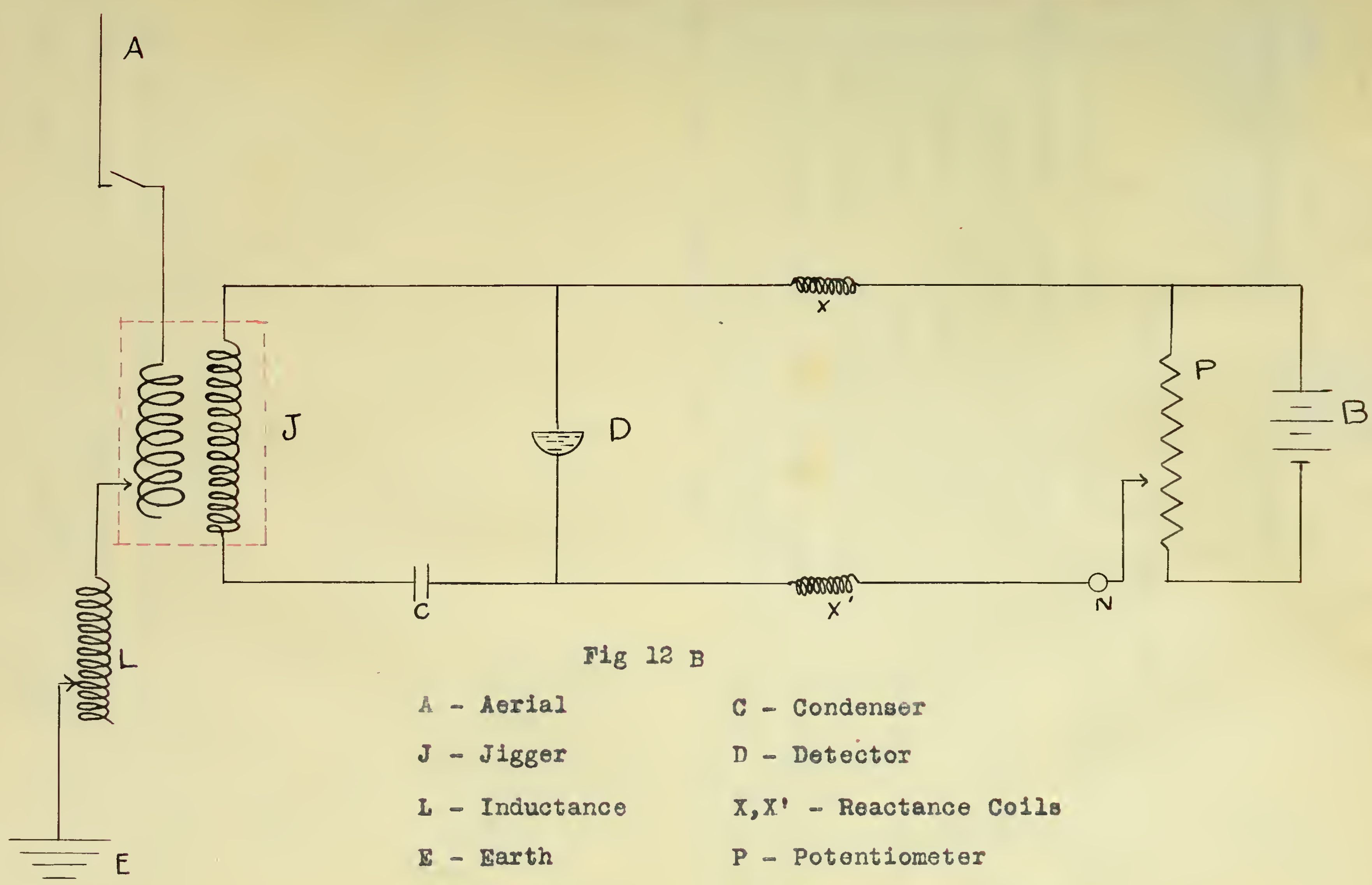

Fig 12 B

A - Aerial	C - Condenser
J - Jigger	D - Detector
L - Inductance	X,X' - Reactance Coils
E - Earth	P - Potentiometer
B - Battery	N - Telephone Receiver

velopment of wireless telegraphy are, Lee De Forrest, Fessenden, Braun, and Fleming all of whom have developed parts of whole systems and improvements on apparatus.

Description of Apparatus.

The system used by the writers was of the syntonic type having apparatus arranged as in figure 12 A & B.

The transformer, see P Figure 13, used is a three kilowatt oil insulated one and has a 110-220 volt primary and a 40,000 volt secondary. It was made by the Thoradson Company of Chicago. It was connected with the primary coils in parallel to the 110 volt 60 cycle alternating current supply of the University. In order to give signals the primary circuit was interrupted by a key shown in diagram in Figure (14).

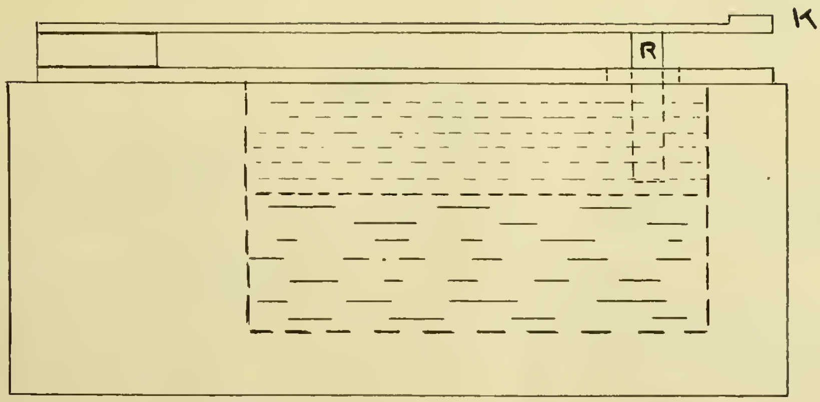

Fig. 14

The key was made from a block of oak wood six inches long six inches wide and three and a half inches thick. In the top of the block near the center was chiseled a hole one inch long three quarters of an inch wide and two and a half inches deep.

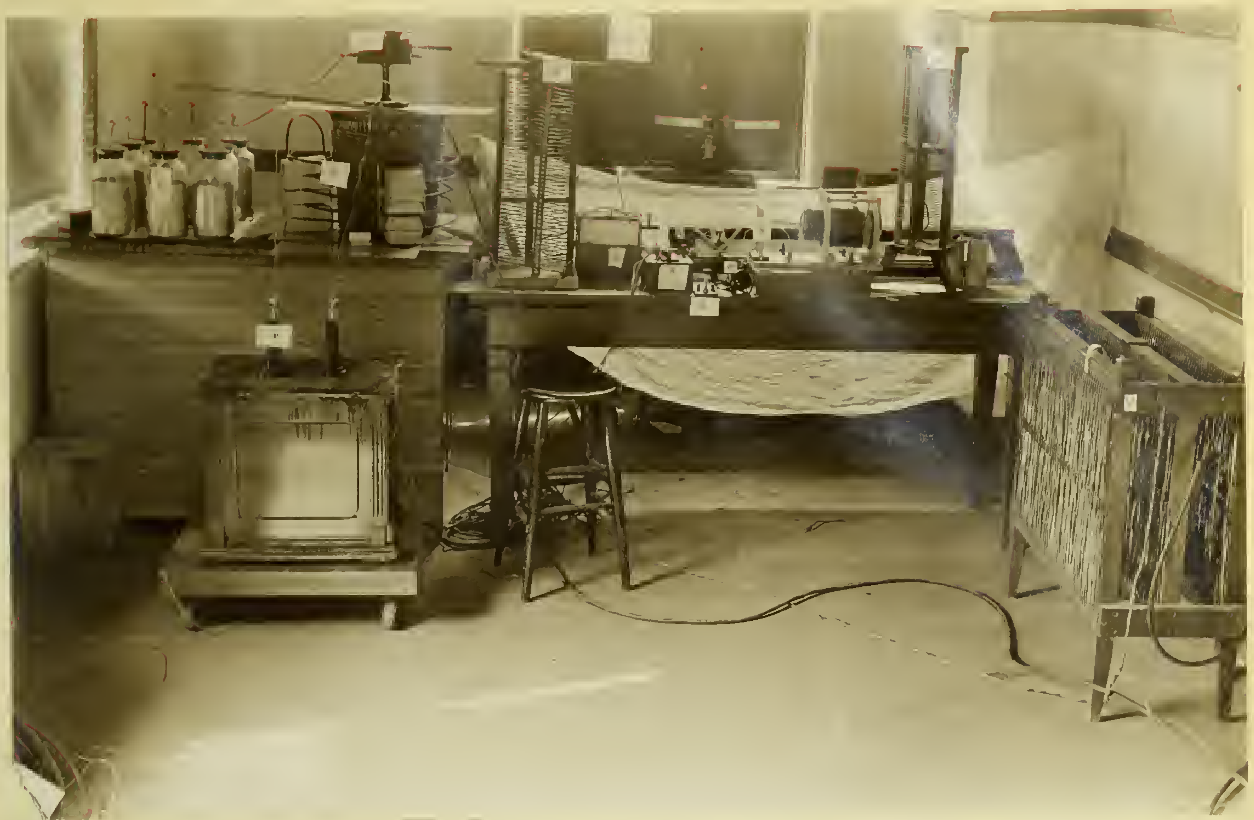

Fig 13

P - Transformer

G - Spark Gap

A - Hot Wire Ammeter

T - Detector

W - Telephone Receiver

I - Receiving Inductance

E - Tesla Coil

R - Sending Inductance

S - Key

K - Potentiometer

N - Jigger

V - Resistance

Over this was placed a hard rubber cover one quarter of an inch thick. One end of a piece of spring brass $\frac{1}{2}$x5x1/16 inches was mounted on another block of rubber and fastened to the end of the cover. At the free end of the brass strip was soldered a one quarter inch copper rod two and a half inches long. The cavity in the block was filled about half full of mercury which was then covered with oil.

By pushing the key K down the rod R dips into the mercury, completing the circuit. When the key is released the circuit is broken and the arc extinguished by the oil. This key was found to work satisfactorily for the currents used which ranged near thirty amperes.

The secondary[1] winding of the transformer was connected to a spark gap across which was connected the primary of the Tesla Coil in series with a battery of Leyden jars. One side of the fine winding of the coil was earthed through a variable inductance the other side going to the aerial.

The secondary of the Tesla Coil was made by winding thirty-five turns of number fourteen duplex lamp cord on a reed waste paper basket sixteen inches long and fourteen inches in diameter. Around this was wound a nineteen inch helix of five turns of number eight rubber covered copper wire, each turn being insulated from the other by the insertion of a cake of paraffin one and a half inches thick.

The spark gap was made by Max Kohl of Chemnitz. Two zinc balls were placed in a glass box four inches wide four inches deep

1. Throughout this paper the primary refers to the coarse winding, the secondary to the fine winding.

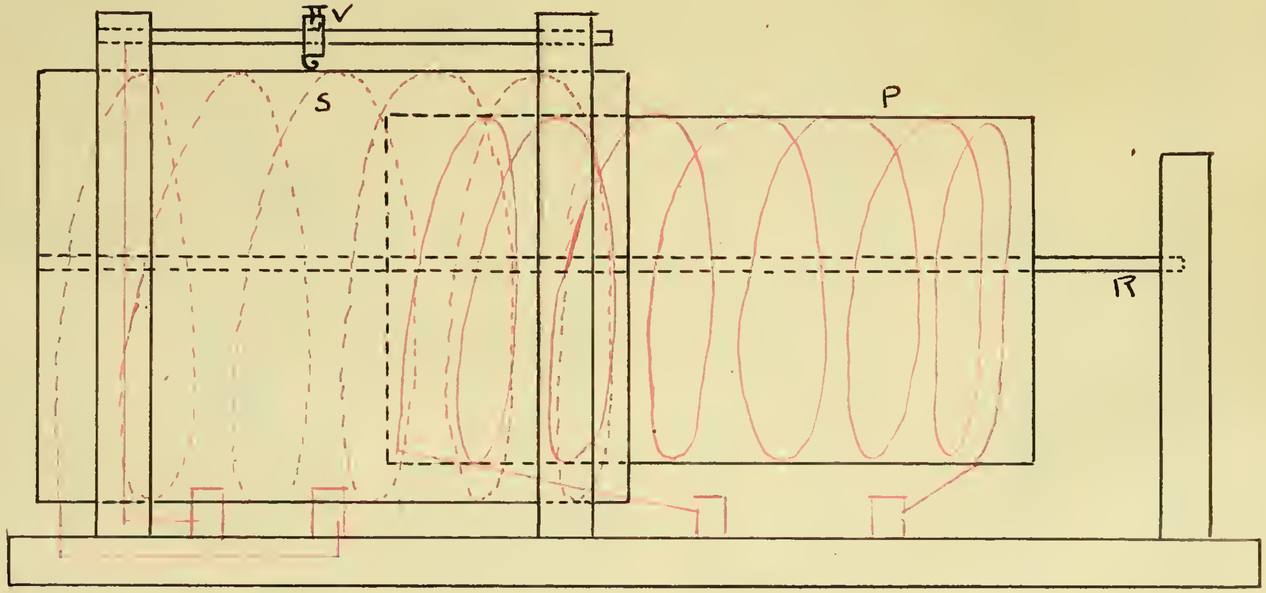

Fig 16

V - Variable Contact

S - Coarse Winding

P - Fine Winding

R - Slider Rod

and six and a half inches long. One ball was rigidly fixed and the spark gap made adjustable by moving the other ball by means of a screw. See Figure (15).

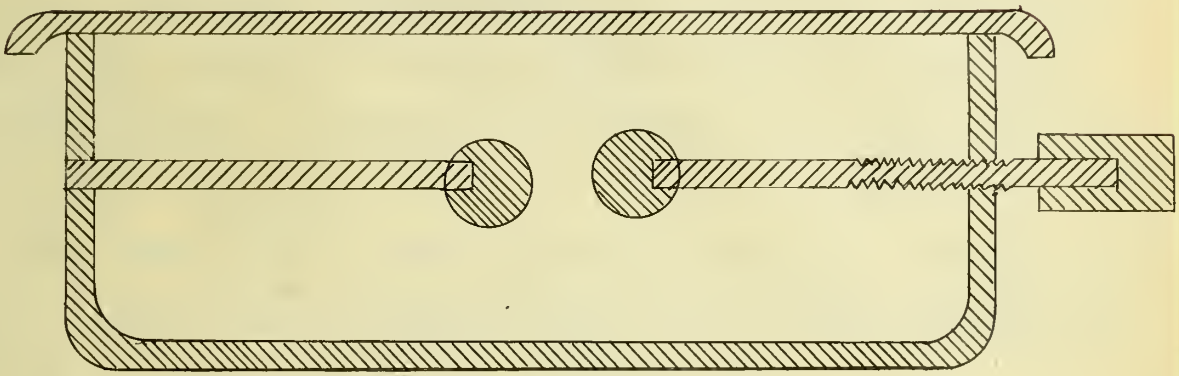

Fig 15

The capacity in the spark gap circuit was composed of eight two quart Leyden jars.

The sending inductance was made by winding forty-five turns of number nine copper wire around a wooden framework nine inches in diameter and twenty-six inches high. (See R Figure 13). A contact clip of sheet brass permitted the use of any part of the coil.

The receiving inductance was constructed by winding eighty turns of number fourteen copper wire on a round wooden form seven inches in diameter and twenty-four inches high. This was also provided with a variable contact clip.

The Jigger (See Figure 16) was made from two glass jars, one five inches in diameter and seven inches long, the other four inches in diameter and eight inches long. The smaller jar was so mounted as to slide within the larger and carried the fine winding which consisted of two hundred and thirty-five turns of number thirty-two cotton-covered copper wire, the larger coil being wound with

one hundred and fifteen turns of number twenty-two cotton-covered copper wire and was equipped with a variable contact.

For receiving the signals an electrolytic detector was used. The electrolyte -- nitric acid -- was contained in a small pressed graphite cup into which dipped a Wollaston wire .0004 of an inch in diameter. Wollaston wire is made of platinum silver plated. The contact of the wire in the acid is adjusted by a micrometer screw. A diagram of the detector is shown in Figure (17).

The choke coils in the receiving circuit were made by winding one hundred turns of number twenty-eight cotton-covered copper wire on a piece of quarter inch iron pipe.

A simple slide wire non inductive potentiometer (See K Figure 13) was used to obtain a variable E. M. F. in the detector circuit. In this circuit a variable capacity was placed. The telephone receiver was of the watch case type and had a resistance of 830 ohms.

The aerial was suspended between the chimney of the University power plant and the north east wing of the Physics building and consisted of four number fourteen phosphor bronze uninsulated wires. For diagram and dimensions see figures 18 and 19.

It was possible to raise or lower the aerial by attaching it to a three eighths inch endless cable running through a pulley at the top of the stack.

The spreaders were made of two by two inch Norway pine covered with three coats of asphaltum paint. The aerial wires were attached to them with quarter inch eye bolts.

Insulators (See Figure 20) were made from hard rubber rods

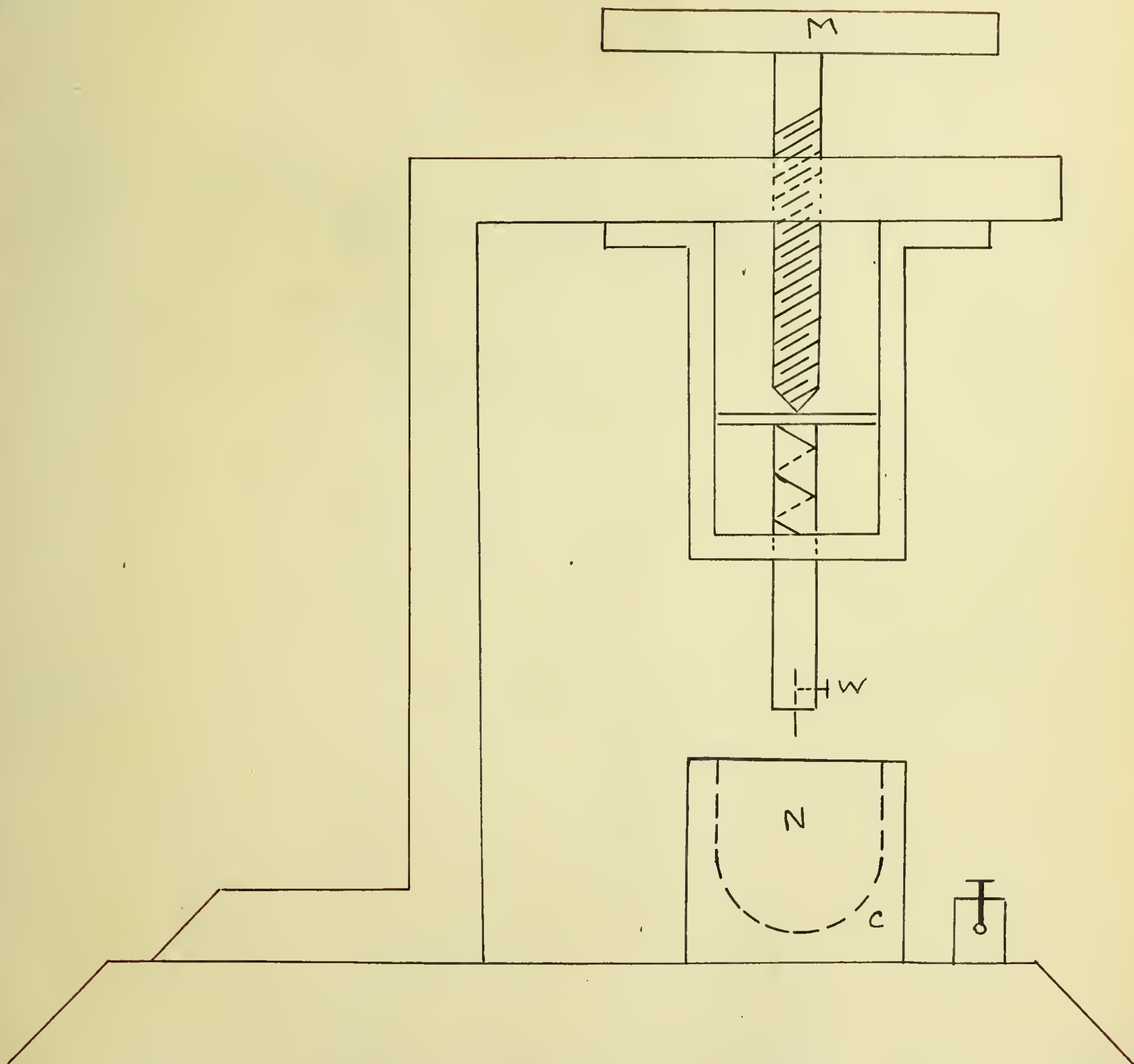

Fig 17

M - Micrometer

N - Electrolyte

C - Graphite Cup

W - Wollaston Wire

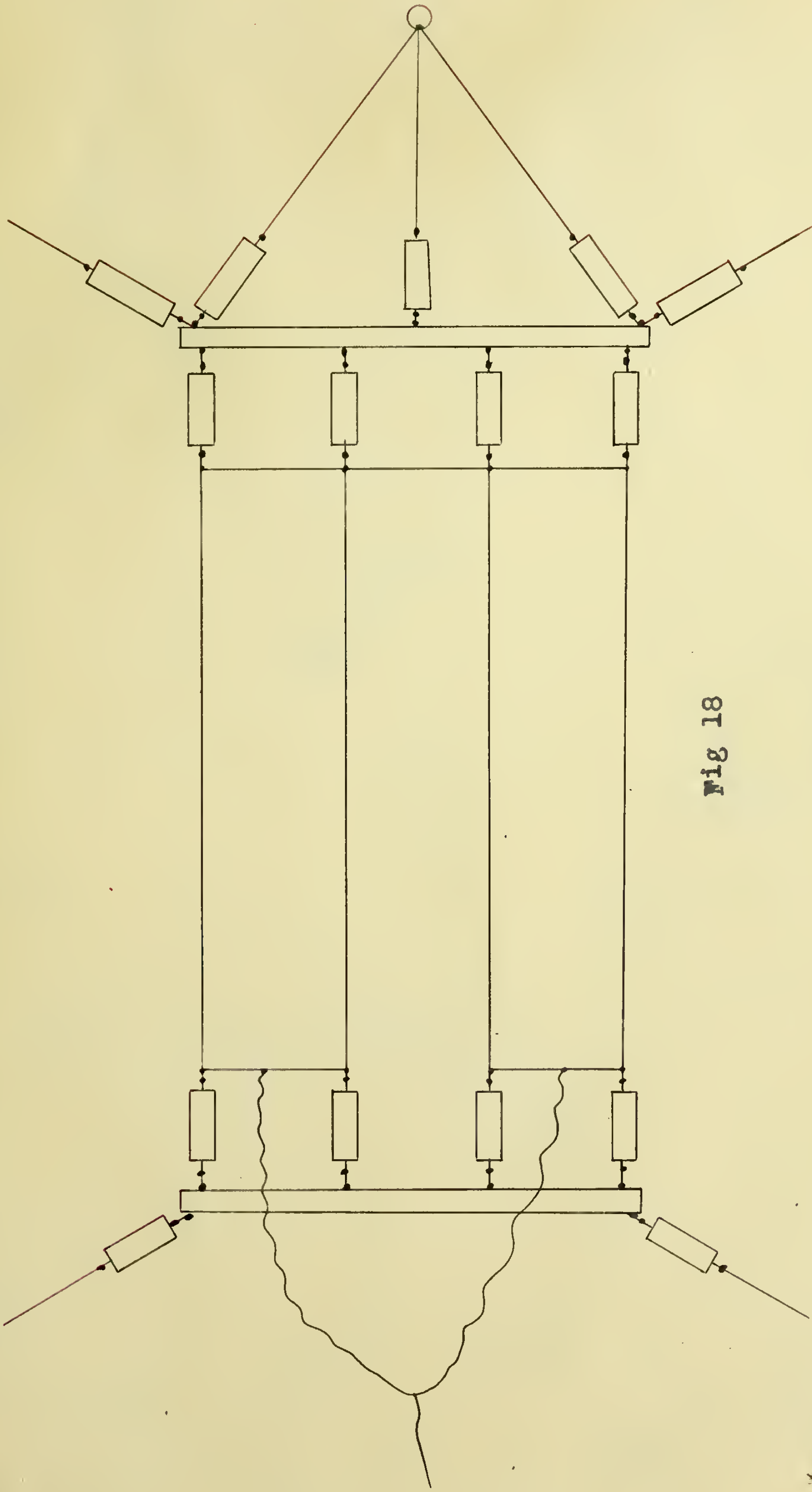

Fig 18

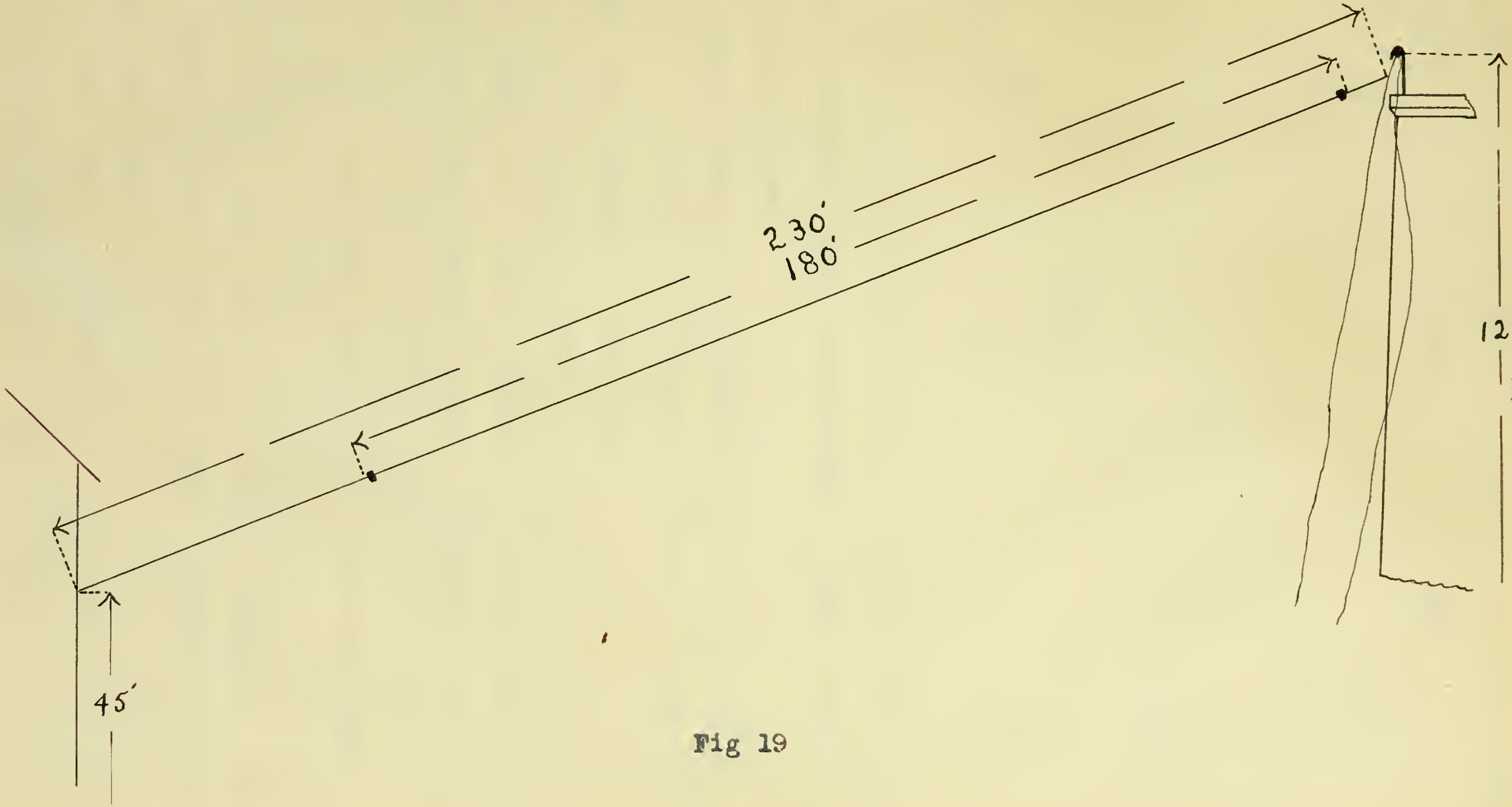

Fig 19

eighteen inches long and one and a half inches in diameter and fitted at the ends with three eighths inch screw eyes.

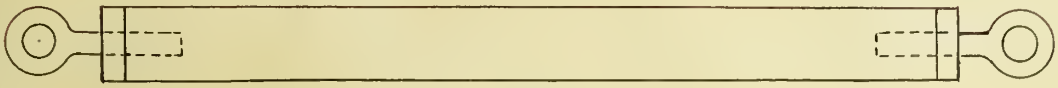

Fig 20

To prevent the aerial from twisting guys with rubber rod insulators as described above were attached to each side of the top and bottom spreaders.

The apparatus was placed in a room on the third floor of the Laboratory of Physics and connection made to it from the aerial with a number nine insulated copper wire.

The method of bringing aerial connection to the building is shown in figure 21. AB is an inch board in two pieces lapping at the center and held together and made adjustable in length by the bolt and slot FG. This board was tightly fitted into the space left by the window when pulled down. The aerial was attached to the rubber rod C which was three quarters of an inch in diameter and two feet long serving as a strain insulator. The loose loop was then brought through a tube D composed of three glass tubes about three feet long telescoped into each other and taped at the ends. The writers brought a solid wire through the tube but since the swinging of the aerial is apt to break the tubes

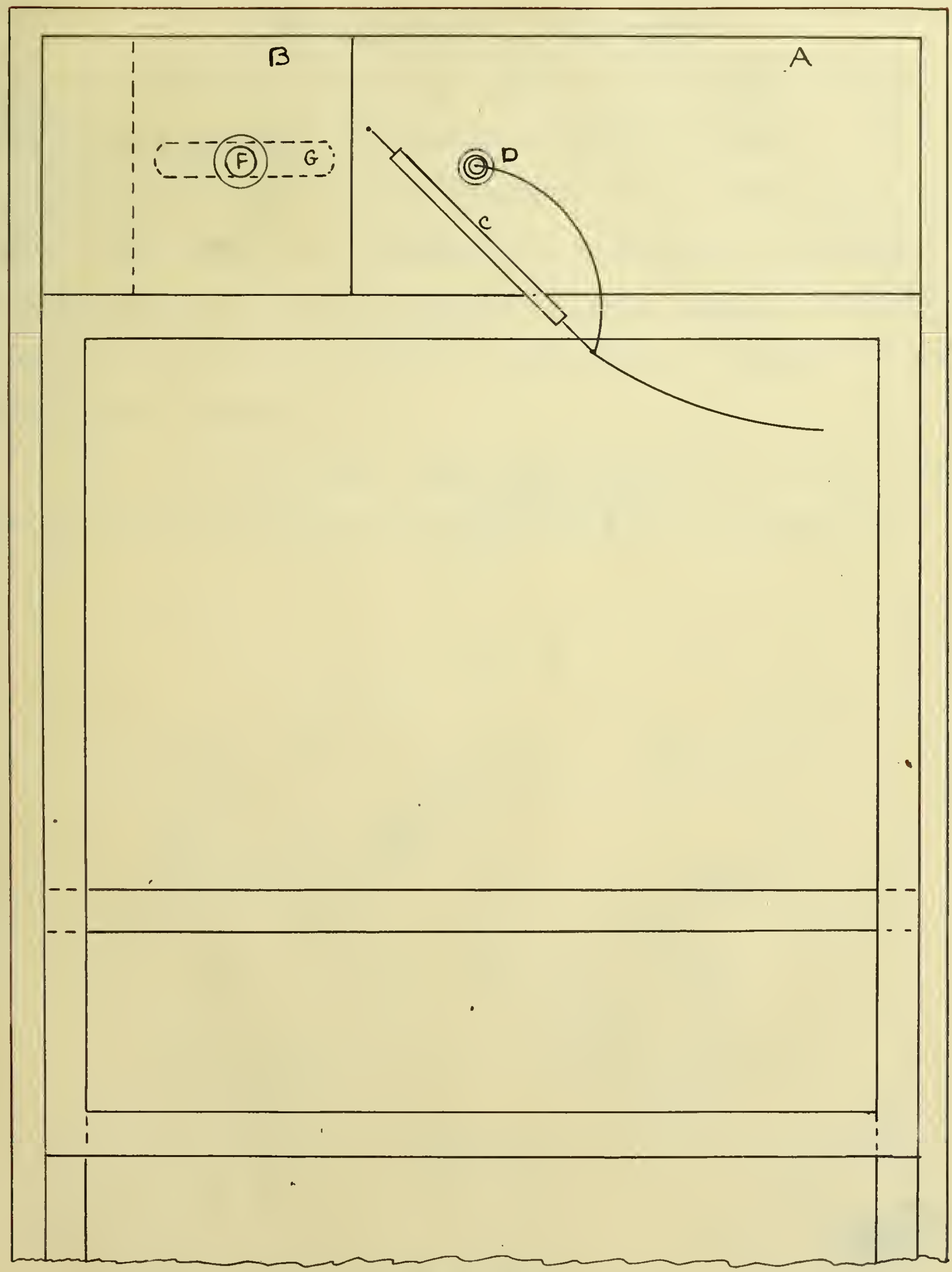

Fig 21

it is suggested that a flexible cord be used from the strain insulator into the building. The hot wire ammeter in series with the aerial was made by the Stanly G. I. Electric Company. Its range was from zero to three amperes.

Determination of Constants.

As previously stated the period of the aerial circuit depends on the capacity and inductance of that circuit. The wave is equal to V×t where V is the velocity of the waves and t the period. Therefore it is necessary to measure the inductance and capacity of the aerial circuit for both sending and receiving connections in order to determine the range of sending and receiving wave lengths.

The inductances were measured by Pirani's method.[1] Diagram of connections for this method is shown in figure 22.

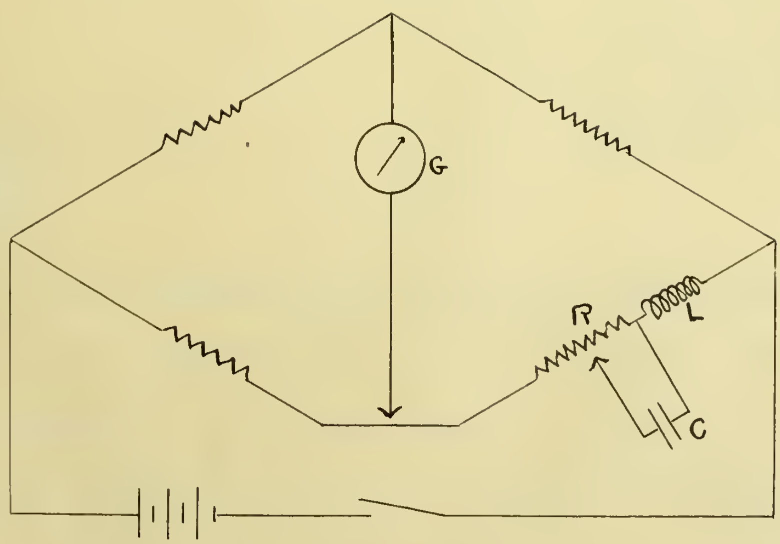

Fig 22

1. Philosophical Magazine March 1910.

The bridge is balanced both for steady and unsteady currents. The inductance is given by the formula,

$$L = CR^2$$

where C is the capacity of the condenser C and R the resistance across which the condenser terminals are connected. This method has the advantage that the resistance of the coil whose inductance is desired need not be known. Capacities were measured by an absolute method.[2] Diagram of connections is shown in figure 23. A and B.

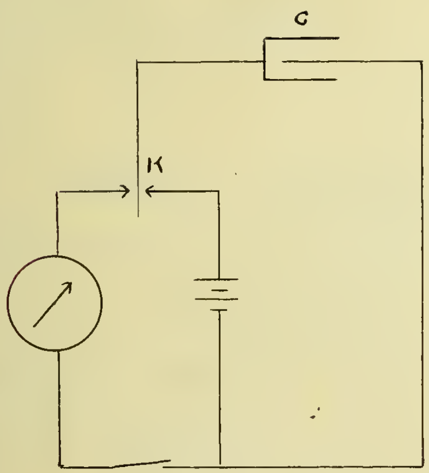

Fig 23 A

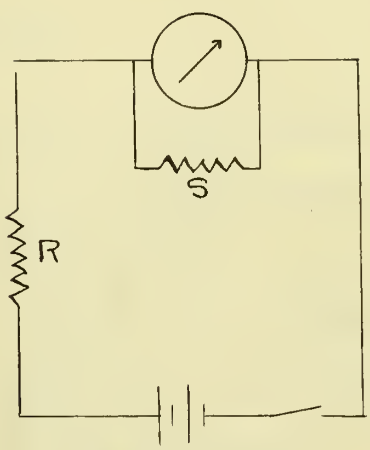

Fig 23 B

K is an electromagnetically operated tuning fork whose period is known. C is the capacity to be measured. If d_1 is the deflection caused by the rapid charge or discharge of the condenser through the galvanometer in figure 23 A and d_2 the steady deflection of the galvanometer, figure 23 B, with the same E.M.F. and resistance R in series with the galvanometer which is shunted

2. Fleming --Manual of Radiotelegraphy, page 282.

Carhart and Patterson, page 230.

with resistance S, then,

$$C = \frac{d_1}{d_2} \times \frac{1}{Rn} \times \frac{S}{S+g}$$

where g is the galvanometer resistance, and n the number of discharges per second.

In the sending circuit the inductances measured were those of the aerial, the sending inductance and secondary of the Tesla Coil. The capacity of the aerial was also determined. To obtain the receiving current constants it was necessary to measure the inductances of the receiving helix and the coarse winding of the jigger.

Manipulation.

Since the frequency of the sending circuit containing the coarse winding of the Tesla Coil is fixed by its capacity and inductance, then in order to get a maximum effect on the aerial circuit the capacity and inductance of the latter circuit must be such that its period will agree with that of the first circuit, that is the two circuits must be adjusted to resonance. For any one wave length the period of the spark gap circuit has a definite value and the frequency of the aerial circuit is made to agree with it by changing the value of the sending inductance. The condition of resonance is determined when a hot wire ammeter placed in series with the aerial reads a maximum.

The receiving aerial circuit must have constants such that its period may be made identical with that of the sending station. The constants are varied by means of the variable receiving inductances. For the same reason the period of the detector circuit must agree with the aerial circuit, and this wave length is

adjusted by means of the variable condenser and the sliding secondary of the jigger coil. The intensity of the current through the detector is regulated by the potentiometer.

Results and Conclusions.

It was the intention of the writers when this thesis was begun to get into communication with Purdue University at Lafayette, Indiana, about ninety miles distant, where a similar station was to be constructed. Owing however to the tardiness of the Purdue station in getting apparatus set up no messages have as yet been received. The work will not be dropped but it is hoped that communication will be established in a few days.

The value of the inductances is found on page thirty-four and a sample calculation of the sending and receiving wave lengths as calculated from measured values as shown on page thirty-five.

Stations having dimensions similar to this station have a rated radius of action of from one hundred to one hundred and twenty-five miles.

The receiving constants are such that it is possible to receive waves of very short length up to those two miles long.

The sending wave length is about seventeen hundred feet but this can be adjusted to agree with the other station if necessary by the insertion or taking away of Leyden jars in the primary circuit.

Measurements.

Trial	C	r	r^2	L (Henries)
		Receiving Inductances.		
1	17.210	4	16	.0002833
2	11.309	5	25	.0002827
3	7.878	6	36	.0002836
			Average:	.0002832
		Sending Inductance.		
1	21.023	3	9	.000189
2	3.514	7.1	50.41	.000177
3	3.514	7	49	.000172
			Average:	.000179
		Tesla Coil - Small Winding.		
1	12.250	5	25	.000306
2	20.123	3.7	13.69	.000289
3	9.333	6	36	.000326
			Average:	.000307
		Jigger - Coarse Winding.		
1	11.408	12.11	146.650	.001673
2	16.170	10.41	108.368	.001652
3	16.870	10.00	100.000	.001687
			Average:	.0018707

Capacity of Aerial.

Trial	d_1	d_2	R	r	g	C (M.F.)
1	16.5	70.5	100000	10	519	.0017625
2	21.0	94.0	100000	10	519	.0016725
3	35.0	161.00	100000	10	519	.0016725
					Average:	.00170317

Calculations of Wave Length.[1]

The length in feet is equal to the velocity times the period.

The velocity V is taken as 186000 miles per second.

t is expressed in seconds and equals $2\pi\sqrt{LC}$, where L is expressed in henries and C in farads.

Capacity of aerial = $.17 \times 10^{-8}$ farads

The sending inductance = $.179 \times 10^{-3}$ plus $.307 \times 10^{-3}$ =

$.486 \times 10^{-3}$ henries.

Hence $t = 2\pi\sqrt{.17 \times 10^{-8} \times .486 \times 10^{-3}} = .1769 \times 10^{-5}$ seconds.

Length = $.1796 \times 10^{-5} \times 186000 = .333$ miles.

Therefore sending wave length = 1758 feet.

Receiving inductance = .0002832 plus .0018707 = .002154 henries.

Capacity = $.17 \times 10^{-8}$ farads.

Hence $t = 2\pi\sqrt{.17 \times 10^{-8} \times .002154} = .1187 \times 10^{-4}$ seconds.

Length = $.1187 \times 10^{-4} \times 186000 = 2.194$ miles which is the maximum receiving wave length.

1. Fleming pp 31, 32.